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Component method in the strength evaluation of cold-formed steel joints

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Abstract

Nowadays, there is a growing tendency in the use of cold formed constructions, which may be explained by good strength to cost ratio. Thus, the goal of this paper is to investigate the strength of cold-formed steel beam-to-column bolted gusset-plate joints. In the paper the model of moment resistance of such joints based on the component method is presented. The calculation of resistance of steel components is based on EN 1993-1-8 and EN 1993-1-1. Two types of gusset plates are investigated: I-shape and T-shape. The developed model is well in line with the full-scale experimental results.

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Keywords: Cold-formed steel joints; beam-to-column joints; moment resistance of joint.

1. Introduction

Cold-formed thin walled sections are widely used as bearing structures in construction sites because of good cost to bearing capacity ratio, fast and easy erection. In most cases thin walled sections are used as purlins, steel trusses and for light weight portal frames. There is a wide variety of cold formed sections (such as Z-sections, C-sections, sigma-sections, omega-sections, etc.) and connections. Cold formed sections can be connected using gusset plates and bolts or directly using bolts [1, 2], screws [3], mechanical clinching [4] and welds.

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In the recent years, researches on thin walled sections have focused on beam-to-column connections with gusset plates [5-11]. Wong and Chung [5] executed beam-to-column sub-frame tests with different configurations of the gusset plate connections. The authors have been investigating the influence of gusset plate thickness, the chamfer presence and the distance between bolts on the strength and stiffness of connections using experimental results. It was found that the geometry of gusset plate has huge influence on the behaviour of the connection. Yu et al. in their job [6] presented semi-empirical design method to calculate rotation stiffness of gusset plate connection. Sabbagh et al. [7-9] executed the tests of the beam to column connections with gusset plate connections under cyclic loads to take into account the different beam's stiffeners. The optimum configuration of stiffeners was proposed. In Bucmys and Daniūnas's paper [10] the stiffness investigation using component method have been presented. The study of papers showed that it is lack of such joint strength investigation using component method.

The goal of this paper was to present a moment resistance calculation model for beam-to-column bolted gusset plate joints (Fig. 1). The resistance of components is determined according to EN 1993-1-3 and EN 1993-1-1. Moreover, another task is to investigate gusset plate behavior using experimental test results.

Fig. 1. The exploded view of the joint under analysis.

2. The model of joint moment resistance calculation using component method

Component method is applied for cold-formed steel beam-to-column joint, as shown in Fig. 1. It is convenient to separate the joint into three springs [10]. The design moment resistance $M_{j,Rd}$ of the presented beam-to-column joint depends on bearing capacities of these springs:

- Beam bolt group in bending and shear $M_{bbg,Rd}$;
- Column bolt group in bending and shear $M_{cbg,Rd}$;
- Gusset plate in bending and shear $M_{gp,Rd}$

- Beam and column sections in bending $M_{c,Rd}$.

The design bending moment resistance depends on the weakest spring of the joint:

$$M_{j,Rd} = \min(M_{bbg,Rd}; M_{cbg,Rd}; M_{gp,Rd}; M_{c,Rd}) \quad (1)$$

2.1. Moment resistance of bolt group

Moment resistance depends of the weakest component of bolt group. Bearing capacities of the components are determined according to the equations presented in Eurocode 3. The moment resistance $M_{bbg,Rd}$ and $M_{cbg,Rd}$ of bolt groups depends on bearing capacities of active components:

- Section web in bearing $F_{bsw,Rd}$;
- Gusset plate in bearing $F_{bgp,Rd}$;
- Bolts in shear $F_{s,Rd}$.

Bolt resistance force could be calculated as the resistance of the weakest component:

$$F_{Rd} = \min(F_{bsw,Rd}; F_{bgp,Rd}; F_{s,Rd}) \tag{2}$$

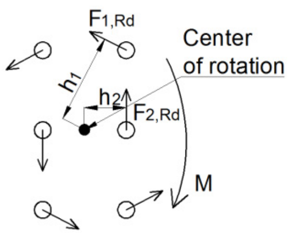

Fig. 2. Reaction forces of bolt group.

The design moment resistance could be calculated using a well-known classical equation:

$$M_{bg,Rd} = \sum_{r=1}^{n} h_r \cdot F_{Rd} \tag{3}$$

where: F_{Rd} – effective design resistance of single bolt r, h_r – distance from the bolt r to the centre of rotation, r – bolt number; n – total number of bolts.

2.2. Moment resistance of gusset plate

The moment resistance of gusset plate was calculated assuming that the joint deforms only in plane and maximum stresses in all failure section (Fig. 3) would reach yield stresses. The design moment resistance of gusset plate could be calculated according well known classical formula:

$$M_{gp,Rd} = \sigma_y \cdot W_{pl} \tag{4}$$

where: σ_y – yield strength of steel, W_{pl} – plastic moment of the weakest section.

Plastic moment of the weakest section (Fig. 3a) when two bolts in a column (5) and three bolts in a column (6) could be calculated:

$$W_{pl} = \frac{t \cdot h^2}{4} - t \cdot d_0 \cdot p_1 \tag{5}$$

$$W_{pl} = \frac{t \cdot h^2}{4} - t \cdot d_0 \cdot p_1 - \frac{t \cdot d_0^2}{4} \tag{6}$$

where: t – gusset plate thickness, h – height of section, d_0 – bolt hole diameter, p_1 – distance between bolt holes.

Fig. 3. Failure sections: (a) A-B two bolts in a column; (b) C-D three bolts in a column.

3. Experimental test

Five specimens were investigated experimentally (Fig. 4). Gusset plates and cold-formed C-sections were made of steel grades S355 and S350GD+Z275 , respectively. The yield and the ultimate strength of both steel grades were measured by way of the coupon tests. As a result, the following values have been obtained for cold formed sections, $f_y = 360MPa$ and $f_u = 540MPa$, and for gusset plate, $f_y = 442MPa$ and $f_u = 570MPa$, respectively. The specimens were connected using 8.8 bolts. The diameter of bolt holes was 1 mm higher than the bolt diameter. The specimens differed by bolt diameter and gusset plate (Table 1).

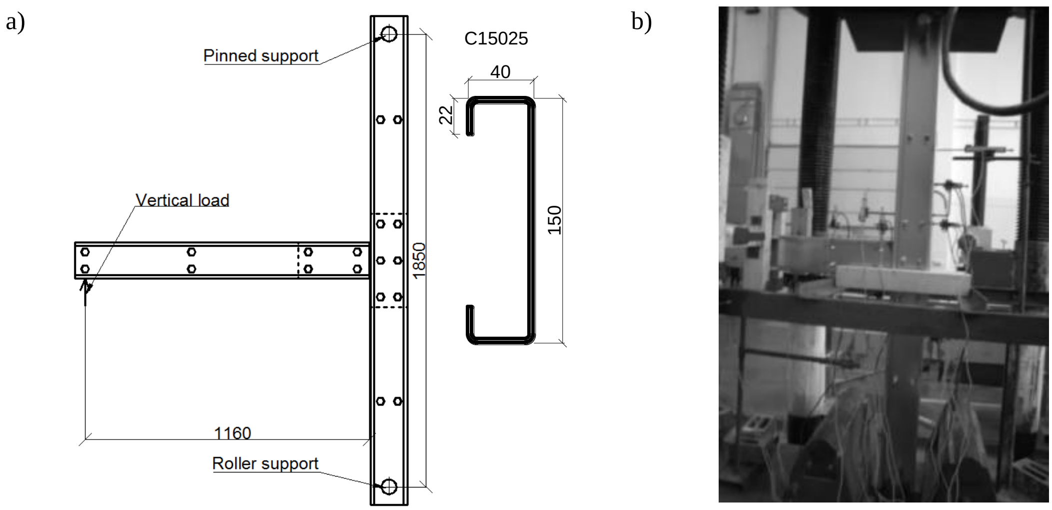

Fig. 4. (a) Geometrical properties of the specimens; (b) Lateral restraints to the specimen.

Table 1. The specimens of experiments.

The specimen	Bolt diameter	Gusset plate form	Thickness of gusset plate
M16 C15025 T8	16	T	8
M16 C15025 T6	16	T	6
M12 C15025 T6	12	T	6

M12 C15025 I10	12	I	10
M12 C15025 I8	12	I	8

Two different types of gusset plates were used in the test: T-shaped and I-shaped. The geometry of the gusset plates and spacing between bolts are depicted in Fig. 5

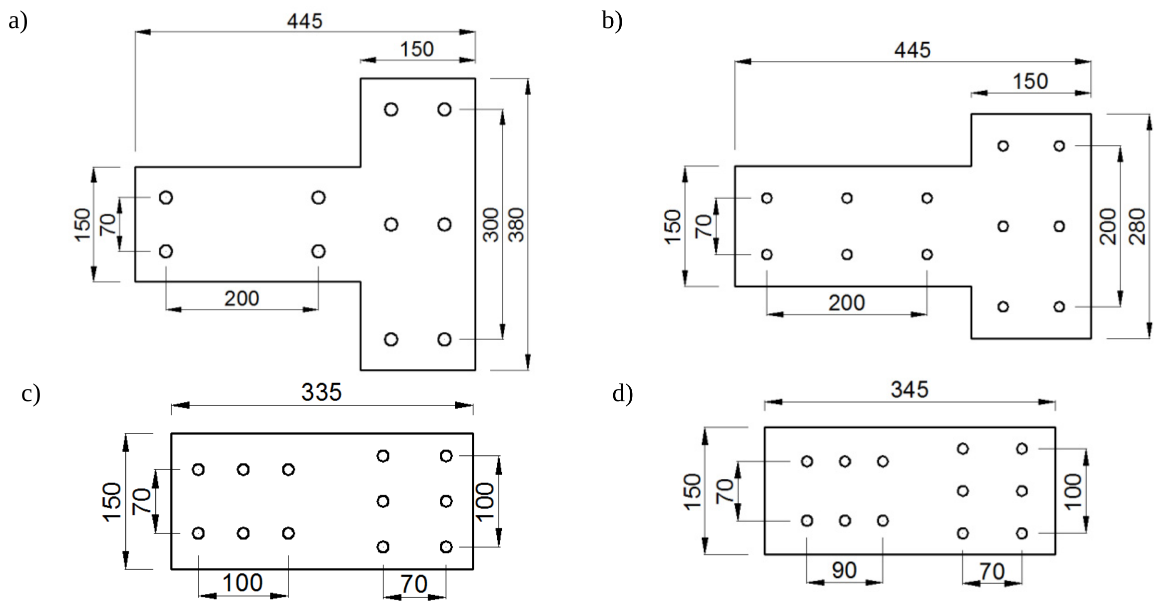

Fig. 5. Geometrical properties of gusset plates: (a) M16 C15025 T8 and M16 C15025 T6; (b) M12 C15025 T6; (c) M12 C15025 I10; (d) M12 C15025 I8.

4. Results of both experimental test and component method

The strength of the joints was calculated using the technique described in Part 2 of the paper. The failure mode of the first three specimens (Table 1) was flexural failure of gusset plate (Fig. 6a) both using component method and experimental results. The experimental failure mode of the 4th and 5th specimens was bolts in shear (Fig. 6b). During demolition of specimen's process it was seen that bearing deformations around bolts occurred. The failure mode of the last two specimens using described model was section web in bearing. Experimental and proposed component method joint moment resistance values are depicted in Table 2.

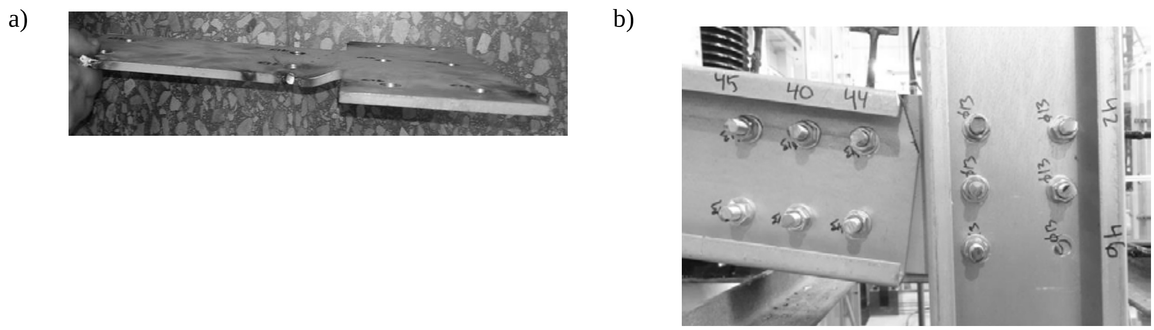

Fig. 6. Failure modes: (a) flexural failure of gusset plate; (b) column bolts in shear and column sections in bearing.

Table 2. The moment resistance and failure modes of the specimens.

The specimen	Moment resistance (Component method)	Failure mode (Component method)	Moment resistance (Experimental test)	Failure mode (Experimental test)
M16 C15025 T8	14.36 kNm	flexural failure of gusset plate	18.62 kNm	flexural failure of gusset plate
M16 C15025 T6	10.78 kNm	flexural failure of gusset plate	11.39 kNm	flexural failure of gusset plate
M12 C15025 T6	10.78 kNm	flexural failure of gusset plate	12.34 kNm	flexural failure of gusset plate
M12 C15025 I10	15.93 kNm	Section web in bearing	17.39 kNm	Section web in bearing
M12 C15025 I8	14.54 kNm	Section web in bearing	14.74 kNm	Section web in bearing

5. Conclusions

The analysis using component method and experimental results of the cold-formed steel beam-to-column bolted gusset-plate joints allow making the following conclusions:

- The new formula of component method for strength calculation of cold-formed steel beam-to-beam gusset plate joint was presented.
- A component method model to calculate the strength of bolt group was presented.
- The proposed model satisfactory correlate with 5 laboratory tests. The failure modes were the same using both methods. The proposed model showed 2% - 22% lower bending moment resistance value comparing with experimental results.

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